RESEARCH DEPARTMENT

# A servo-controlled, one-line delay for 625-line television signals

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*'A SERVO-CONTROLLED, ONE-LINE DELAY*
*FOR 625-LINE TELEVISION SIGNALS'*

Page 1, Section 2.1, line 2: for 'field' substitute 'line'.

RESEARCH DEPARTMENT

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(1965/51)

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# A SERVO-CONTROLLED, ONE-LINE DELAY FOR 625-LINE TELEVISION SIGNALS

SUMMARY

This report describes apparatus designed to delay a mains-locked 625-line television signal by a period equal to the duration of one television scanning line. The equipment was designed primarily for use in a line-store standards converter but has other applications in television engineering. A fused-quartz ultrasonic delay* is employed as the main delay element together with a variable video delay compensating automatically for small changes in the television line duration.

## 1. INTRODUCTION

In order to ensure that the information carried by the output signal of a standards converter is correctly located spatially it is necessary to interpolate between the lines of the input signal.[1] In one method of line-store standards conversion,[1] the functions of storage and interpolation are performed separately and the interpolation arrangement employs one or more line-period delays. It was for this application that the equipment described in this report was designed but it is of interest to note, however, that the equipment also has other uses and in particular has applications in connection with the vertical aperture correction of television signals.

## 2. CHOICE OF DELAY

### 2.1. Variable Delays

In the present application, it was desired to delay a 625-line television signal by precisely the duration of one television ~~field~~ line. When the television system is synchronous** however, the actual line period is determined by the frequency of the mains supply and it has been found[2] that deviations exceeding 0·5% from the nominal value rarely occur for more than 1% of the time. An adjustable delay was needed, therefore, to compensate for variations in line duration and consideration was first given to the use of a mercury delay[3] controlled by a suitable servo system, but this was rejected mainly on account of its unsuitability for service use.

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* To avoid confusion, the term 'delay' is used in preference to 'delay line' when describing equipment used to delay a television signal. The word 'line' refers only to a television scanning line.

** A television system is said to be synchronous when the field frequency is synchronised to the mains supply frequency.

It was decided to use a fused quartz ultrasonic delay[4] to provide the major part together with an adjustable electrical network for the variable remainder of the delay. This decision was made possible by the availability of a commercial, variable video-delay unit* employing variable-capacitance diodes (varactors) as the shunt circuit elements. In this unit, adjustment of delay is achieved by control of the bias potentials applied to the diodes and a variation in delay of approximately ± 10% can be obtained without serious loss of performance. Control of the delay was made automatic so that the apparatus was able to follow variations in line duration without manual adjustment. Amplitude modulation was chosen for the carrier used in the quartz delay, although it was realised that the use of frequency modulation might enable the required performance to be achieved with greater ease. However, with a restricted development time available and with a number of unknown factors involved, it was thought that an attempt to use frequency modulation was not justifiable.

### 2.2. Fused-Quartz Fixed Delays

The delay unit described in this report was commercially manufactured specially for the purpose. It employs fused quartz as the transmission medium and piezo-electric crystals as the electro-mechanical transducers. The insertion loss over the frequency band from 30 Mc/s to 40 Mc/s was 54 dB (between 75 ohm terminations) and the level of spurious signals was -40 dB relative to the main signal. Spurious signals arise due to the existence of more than one path through the quartz delay, but a discussion of this aspect is outside the scope of this report and reference should be made to the literature[5,6] for further information.

### 2.3. Performance Requirements of the Delay Equipment

A test specification for the delay equipment, formulated from the requirements of the line-store standards converter, is described in the Appendix.

In addition to the very low waveform distortion required, it was felt that the overall gain stability should be sufficiently high to eliminate the need for frequent adjustment. To this end, all the amplifiers in the equipment incorporated adequate negative feedback and high-stability components were employed where necessary. To improve the long-term stability still further, a unit providing automatic gain control (a.g.c.) was included. Without a.g.c., the range of gain variations over a period of three weeks was found to be less than 1%. The degree of improvement due to the addition of a.g.c. is not certain, but measurements indicated that variations in gain due to normal fluctuations in ambient temperature and supply voltages would not be more than 0·5%. In fact, during the first nine months of operational service in a line-store standards converter, no adjustment of gain was found necessary, indicating a long-term stability of 0·5% or better. It should be noted that, whereas a.g.c. normally functions to compensate for unwanted variations in signal input, the action of the a.g.c. in this equipment is to reduce unwanted variations of gain. The exclusive use of semi-conductors throughout the equipment has proved beneficial in reducing the size, temperature, warm-up time and routine maintenance.

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* 'Amtec' unit, manufactured by the Ampex Corporation.

## 3. DESCRIPTION OF THE DELAY EQUIPMENT

### 3.1. General Description

The complete video delay equipment consists of three different delay systems in cascade. The first uses a fused-quartz delay and provides some 95% of the required delay. At a carrier frequency of 35 Mc/s, its bandwidth is sufficient to accommodate the amplitude-modulated double-sideband transmission of a 625-line television signal. An envelope demodulator recovers the video signal which then passes to the variable video delay which is servo-controlled to follow fluctuations in the line duration over a range corresponding approximately to the range of variation to be expected in a synchronous television system. A third unit contains short sections of delay which can be selected manually to accommodate larger changes in the mains frequency if required.

A block diagram of the complete equipment is shown in Fig. 1. The sync-pulse phase-discriminator detects the timing error between the input and output line-synchronising pulses, the output pulses having been delayed by one line-period. An error signal is then fed to the variable video delay which compensates the timing error.

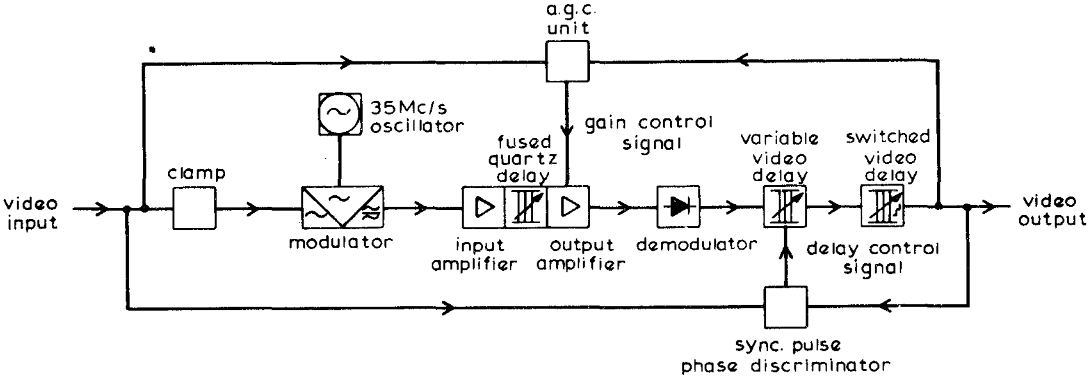

*Fig. 1 - Servo-controlled one-line delay*

The total video delay provided by the equipment is compensated to an accuracy of one tenth of the duration of one picture element (10 ns).

The input and output video-signal amplitudes are compared in the a.g.c. unit. According to their difference, a gain-control bias is applied to the output amplifier which varies in gain to compensate for the gain error.

Much of the equipment consists of conventional apparatus and only those units believed to be of special interest are described in the following sections. Photographs of the quartz-delay unit together with its input and output amplifiers are shown in Figs. 2 and 3. Heavy screening was used throughout, mainly to reduce the

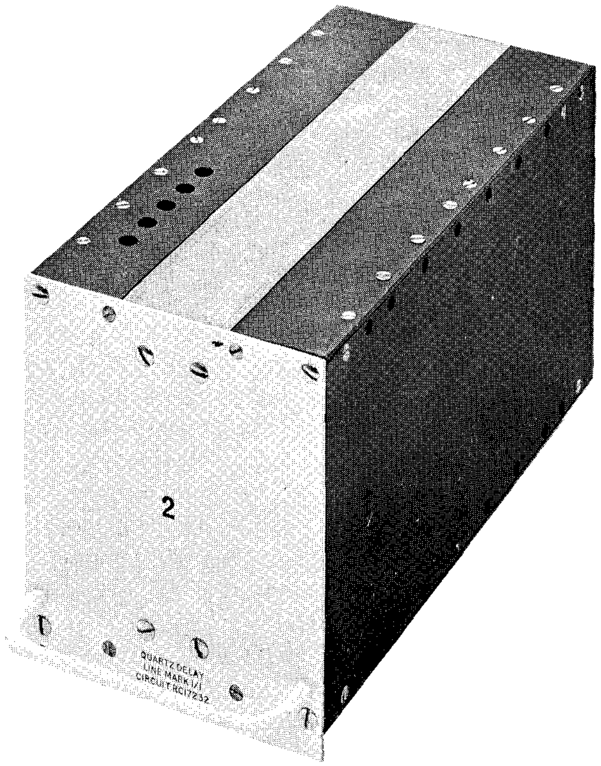

*Fig. 2 - Fused-quartz delay assembly*

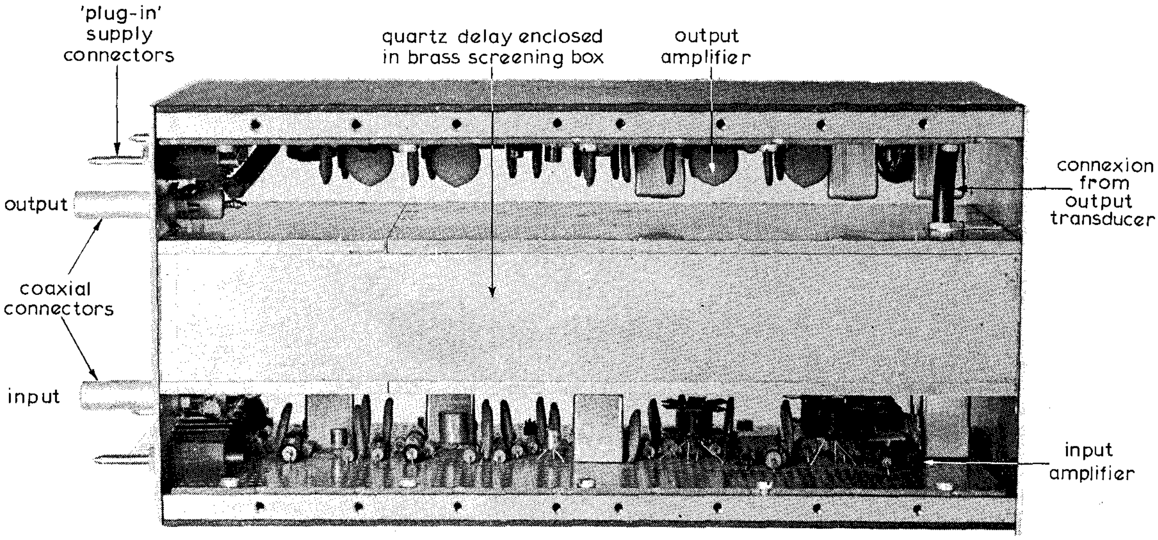
'plug-in' supply connectors
quartz delay enclosed in brass screening box
output amplifier
connexion from output transducer
output
coaxial connectors
input
input amplifier

*Fig. 3 - Fused-quartz delay assembly with covers removed*

effects of unwanted coupling between input and output. The overall gain of the delay unit was 0 dB over the frequency band 30 Mc/s to 40 Mc/s.

Later equipment operating on the same principle has been designed to produce, simultaneously, delays of both one and two line periods.

### 3.2. Input Amplifier

It was found that an output video signal-to-noise ratio of about 60 dB could be obtained when the input transducer was driven with a modulated r.f. signal of about 7 V d.a.p. and this was used as a practical design basis. All the transistors in the amplifier operate in class 'A' with current feedback to minimise non-linear distortion and to preserve gain stability. A circuit diagram is shown in Fig. 4. The first three stages are stagger-tuned to provide the necessary bandwidth, the driver and push-pull output stages use wideband transformer coupling and a top-capacitance-coupled band-pass network feeds the input transducer of the delay. The transducer presents an almost purely capacitive impedance and is used to form one of the capacitive elements of the band-pass network.

### 3.3. Output Amplifier

A circuit diagram of the output amplifier is shown in Fig. 5. A band-pass network couples the output transducer of the quartz delay to the input of the amplifier and for reasons of stability and simplicity, the common-base configuration is used in all amplifying stages except the third. In the third stage, a common-emitter amplifier precedes a shunt-connected diode, D1, which is used for automatic gain-control purposes; the standing current in the diode is controlled by the a.g.c. bias via transistor TR4. However, since the diode is in shunt with the signal path (via C19) and its incremental impedance depends upon its standing current, it follows that the a.g.c. bias controls the gain of the amplifier. The cascade arrangement of TR3 and TR5 presents a fairly low impedance to the a.g.c. diode which restricts its range of control and minimises its effect on the response/frequency characteristic. Conflicting requirements governed the choice of position of the diode; the signal voltage must be small in order to avoid excessive non-linear distortion, but the use of too small a signal would result in an impaired signal-to-noise ratio. In practice, a voltage gain of 10 dB before the cascade stage was found to be a reasonable compromise.

To permit some equalisation of the overall response/frequency characteristic, one stage in the amplifier is tuned; the remainder use wideband-transformer coupling, the final stage having an output impedance of 75 ohms over the passband. The amplifier, including the input network, has an overall gain of 24 dB, and this can be varied by ± 3 dB by means of the 'gain control signal', Fig. 1.

### 3.4. The Variable Video-Delay Unit

This unit comprises a commercially manufactured, lumped-element, 3 $\mu$s delay in which the shunt capacitance is provided by variable-capacitance semi-conductor diodes (varactors) which control the capacitance and hence the delay of the unit. Unfortunately, the characteristic impedance of the line also changes with capacitance which demands that variations be kept small in order to minimise reflections due to

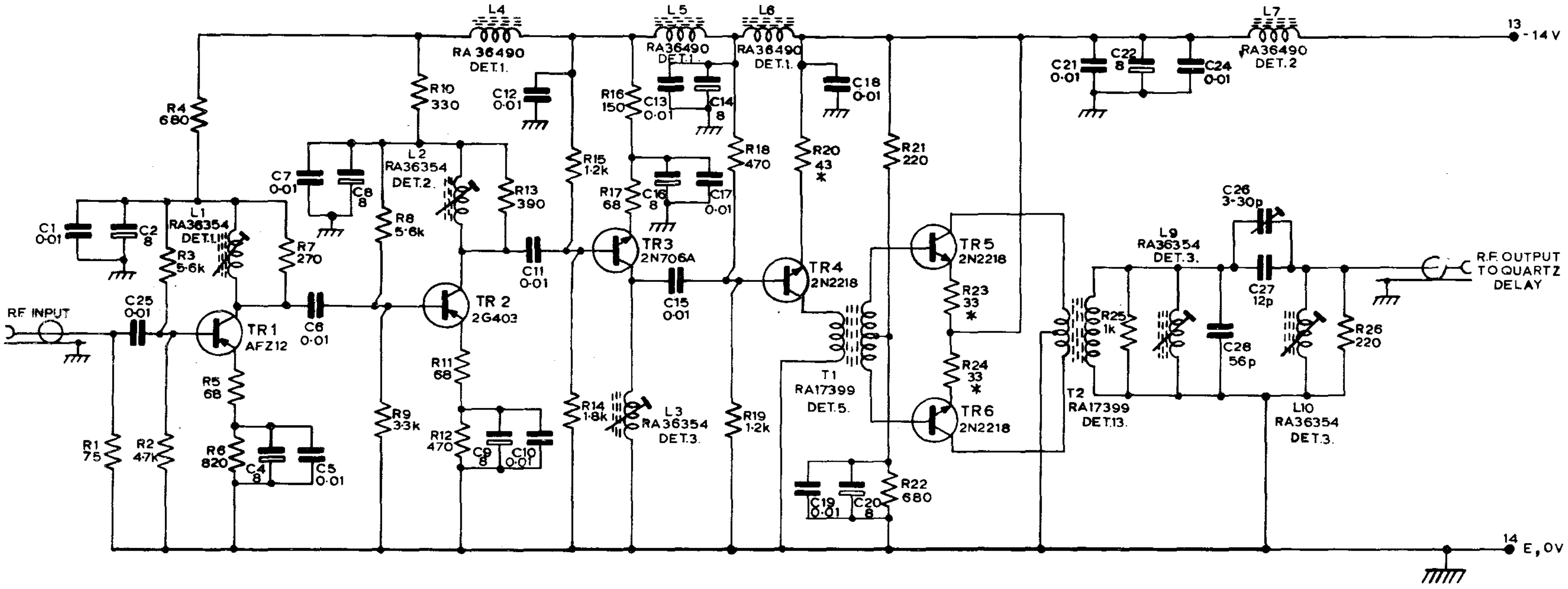

Fig. 4 - Input amplifier

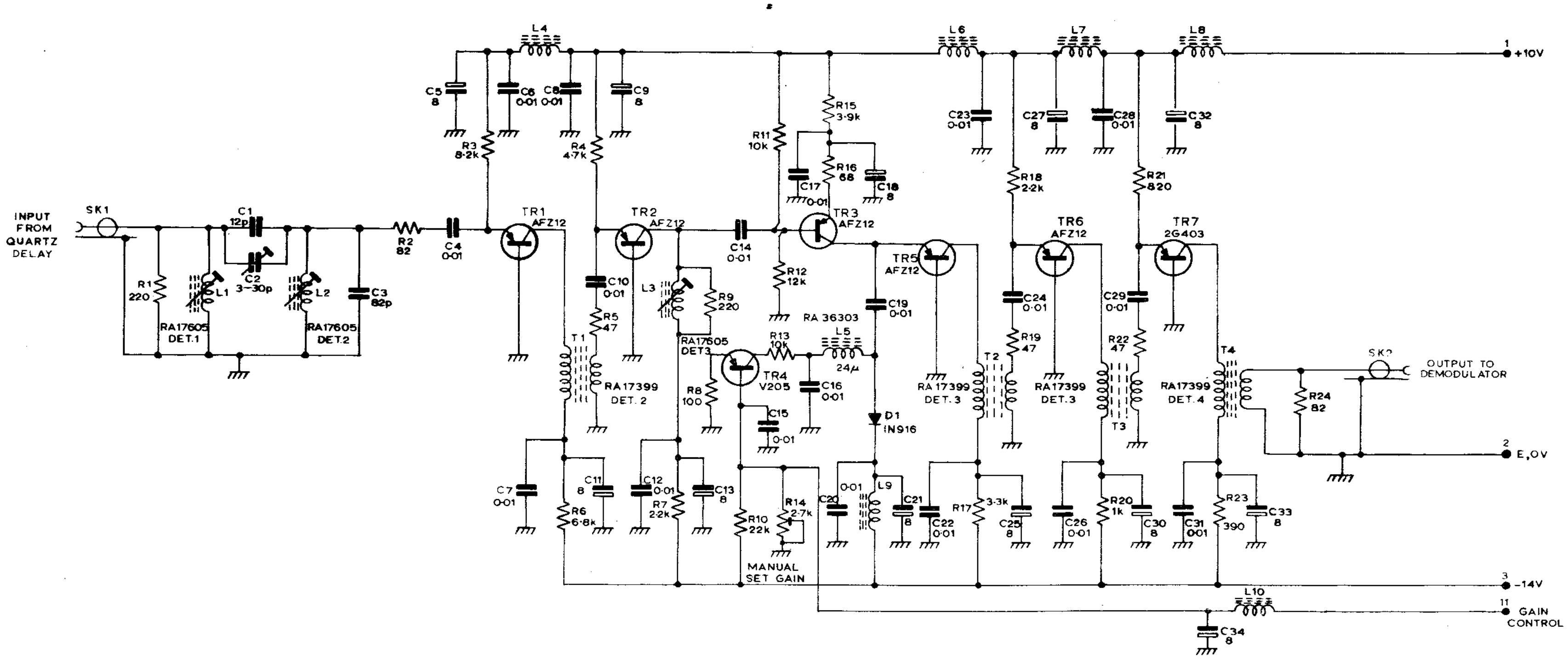

*Fig. 5 - Output amplifier*

mis-termination. The permissible range of delay variations was determined experimentally and limits were imposed when the amplitude of the strongest reflection reached -40 dB relative to the main signal. The variation achieved using this criterion was ± 10% of the mean delay of 3 μs. This was considered adequate to meet most situations, since it allowed correction for mains frequency variations of ± 0·25 c/s, but a manually-switched delay (see below) was incorporated to deal with the rare cases of large mains-frequency errors.

### 3.5. The Sync-Pulse Phase Discriminator

Extreme care was required in the design and construction of the discriminator in order to minimise long-term drifting of the output control-voltage and, where necessary, silicon semi-conductor devices were used, in preference to germanium ones, together with other high-stability components.

In attempting to control the delay to be one line period ± 10 ns the unit must in the first place generate fast pulses, preferably with rise times less than 20 ns, accurately timed with respect to the incoming and delayed sync trains.* These are obtained by two clamped sync-separators followed by high-speed Schmitt triggers.

Sawtooth waveforms derived from these pulses are compared in a long-tailed-pair circuit (see Fig. 6) and the resulting positive or negative pulses are d.c.-restored, smoothed and amplified to become finally the offset push-pull control signal for the variable video delay.[7]

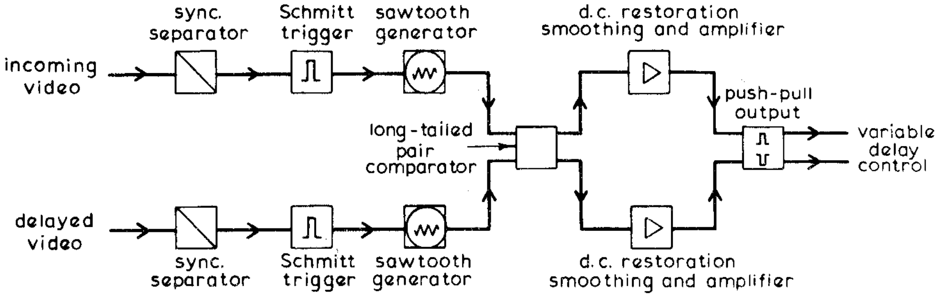

*Fig. 6 - Sync-pulse phase discriminator*

The loop gain of the discriminator system, formed by the discriminator and the variable delay, is of the order of 100 times, so that an error of up to 500 ns with no control can be reduced to 5 ns with the loop closed.

### 3.6. Switched Delay Unit

A manually-operated switch selects one of three positions providing 0, 0·3 μs or 0·6 μs of delay. Cascaded pairs of second-order all-pass networks[8] with maximally-flat group delay are assembled in two groups, each providing 0·3 μs of delay. A constant-resistance equaliser corrects the amplitude/frequency response of each line, and bridged-T attenuator sections enable the insertion loss at the three switch positions to be identical.

* It should be noted that the rise time of line-sync pulses in the 625-line television system is 300 ns.

A meter is provided to monitor the bias on the variable video-delay unit to give the operator a visual indication of the amount of fixed delay required.

### 3.7. The Automatic Gain-Control Unit

The automatic gain control maintains an overall video gain of unity for the complete delay equipment. Fig. 7 is a block diagram of the a.g.c. unit. Subtraction of the delayed and undelayed signals yields a difference output in which the synchronising-pulse magnitude and polarity describe the error in overall gain. The subtractor output is amplified and clamped before the synchronising pulses are sampled. The error signal thus obtained is amplified, integrated over many pictures lines, and fed at low impedance to the gain-controlling element in the quartz-delay output amplifier, thus completing the a.g.c. loop which has a gain of 500. During the field-blanking interval, the action of the a.g.c. is inhibited in order to avoid errors which would result from the subtraction of unlike waveforms during parts of the equalising and field-pulse periods. To facilitate maintenance, indicator lamps are provided which are illuminated automatically when the limits of the a.g.c. range are approached. Operators thus receive warning of incipient faults where a slow change of gain is occurring and action can be taken to prevent breakdown or loss of performance.

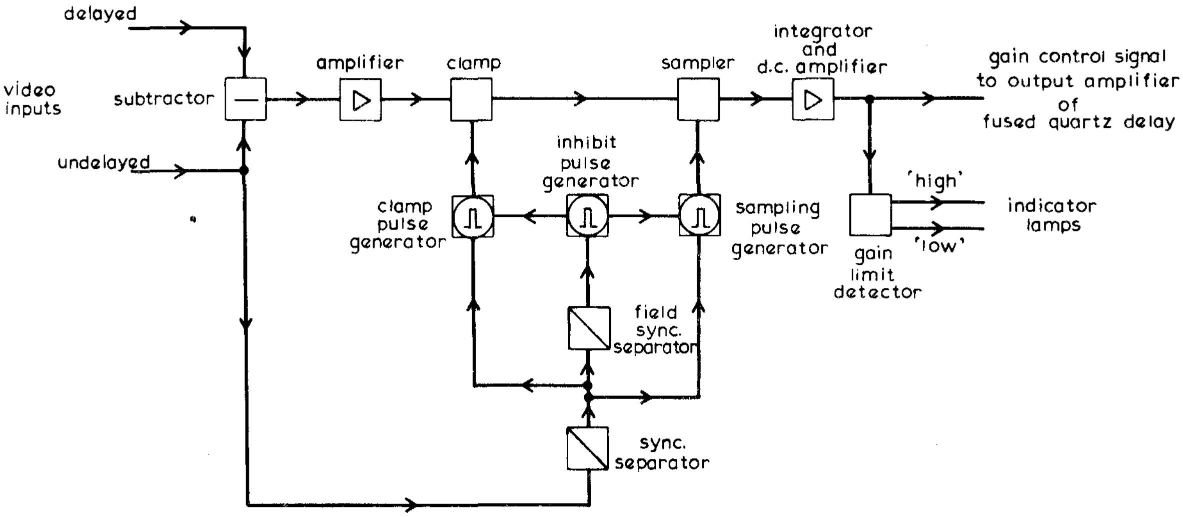

*Fig. 7 - A.G.C. unit*

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# *APPENDIX*

## *Test Specification*

For optimum operation of the interpolator in a line-store standards converter, the performance requirements of the one-line delay are particularly stringent. The interpolator modulating-function of the standards converter has a periodicity determined by the difference between the output and input line frequencies and any distortion within the delay path will result in a spurious signal at this frequency in the output. The effect is most easily understood if the input signal to the standards converter is assumed to be describing a uniform, grey scene. In this case, the difference between the input and output signals of the delay should be zero, because all active lines of the signal are alike and interpolation is not then necessary to provide the correct output signal for the new standard. If the difference signal is not zero, however, due to, say, amplitude non-linearity or an error in gain in the delay path, the signal fed to the re-distributing store of the standards converter will contain this spurious difference signal, modulated at the low frequency associated with interpolation and visible on the output picture as a coarse horizontal pattern.

The formulation of a performance specification for the delay section of an interpolator was undertaken at an early stage, using simulation techniques, and the essential details of the resulting specification were as follows.

Using a multi-burst* test signal, the input and output signals from the delay were to be capable of being subtracted (one from the other) to leave a residual signal not greater than -26 dB relative to either signal alone.** The delay time was to be correct to within ± 10 ns over the working range of ± 0·3 μs.

The main part of the specification thus included the simultaneous effects of non-linearity, the response/frequency and phase/frequency characteristics of the delay equipment as well as the absolute gain and signal-to-noise ratio. The performance in any respect was thus required to be considerably superior to that dictated by the overall figure of -26 dB. In addition, it was necessary that the limits of the specification were not exceeded during eight hours of unattended operation.

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* A 'multi-burst' signal comprises a television video waveform, without field information but complete with line-synchronising pulses. The picture information is formed from a mid-grey mean value, to which is added a series of six 'bursts' of sinusoidal signal, in this instance covering a range of frequencies from 0·5 to 4·5 Mc/s, each burst having a peak-to-peak excursion from black level to white level.

** For this test, it was permissible to trim the value of delay manually to give minimum output, the tolerance upon the absolute delay being separately assessed.

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